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PERFORMANCE OF A CLASS III BARREL-STAVE FLEXTENSIONAL TRANSDUCER DRIVEN BY AN INTEGRATED ACTUATOR

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Defence R&D Canada
Technical Memorandum
DREA TM 2000-025
November 2000

National Defence Défense nationale

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Abstract

A Class III barrel-stave flextensional transducer driven by an integrated actuator was tested in seawater at the DREA Acoustic Calibration Facility. This broadband sonar transducer has four coupled TVR resonance peaks below 10 kHz due to a longitudinal and three flexural vibrational modes. Below 3 kHz the response of the new transducer is similar to that of a Class III barrel-stave transducer driven by a conventional stack. In the frequency range from 3 to 5 kHz the IAD transducer produces as much as 6 dB more sound pressure level than the conventional Class III due to better coupling between the second flexural and longitudinal modes. A deep notch in the TVR at 8 kHz may be due to the sensitivity of lobes in the directivity pattern to vibrational asymmetries caused by the cable potting.

Résumé

Un transducteur flextensionnel à douves de classe III commandé par un dispositif de commande intégré a été mis à l'essai dans l'eau de mer à l'Installation d'étalonnage acoustique du CRDA. Ce transducteur de sonar à large bande a quatre crêtes de résonance TVR (sensibilité par volt) couplées inférieures à 10 kHz, qui sont associées à un mode vibratoire longitudinal et à trois modes vibratoires de flexion. En dessous de 3 kHz, la réponse du nouveau transducteur est semblable à celle d'un transducteur flextensionnel à douves de classe III commandé par une chaîne classique. Dans la plage de fréquences allant de 3 à 5 kHz, le transducteur commandé par IAD produit un niveau de pression sonore dont la valeur maximale dépasse de 6 dB celle du transducteur de classe III classique grâce à un meilleur couplage du deuxième mode de flexion et du mode longitudinal. Une baisse marquée de la sensibilité par volt à 8 kHz peut être due à la sensibilité des lobes du diagramme directionnel aux asymétries vibratoires causées par l'enrobage du câble.

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Executive summary

The Class III barrel-stave flextensional transducer is a broadband, high-power underwater sound source that has both military and non-military applications. The transducer is currently the subject of a joint Technology Research and Development Project between the U.S. Department of Defense and the Canadian Department of National Defence. The goal of this project is to build broadband transducers driven by high energy density materials for use in littoral water sonar systems.

The broadband Class III transducer has been integrated into a marine mammal playback apparatus known as the Broadband Acoustic Transmission System (BATS). Developed jointly by DREA and Sensor Technology Limited in Collingwood, Ontario, the BATS has been used by researchers at Dalhousie University in Halifax, Nova Scotia to study the vocalisations of various whale species. To date, research carried out involving BATS includes vocal mimicry in long-finned pilot whales (Cape Breton, summer 1999), dialect structures in sperm whale codas (Chile, throughout the year 2000), and acoustic localisation of endangered northern right whales (Bay of Fundy, summer 2000).

Two low-cost integrated actuator drivers (IADs) supplied to DREA by Sensor Technology were incorporated into an experimental Class III barrel-stave transducer. The IAD transducer was calibrated in seawater and the performance was compared to a similar unit driven with a conventional stack.

Jones, D.F, Reithmeier, C.G. 2000. Performance of a Class III barrel-stave flextensional transducer driven by an integrated actuator. DREA TM 2000-025 Defence Research Establishment Atlantic.

Sommaire

Le transducteur flextensionnel à douves de classe III est une source sonore sous-marine de grande puissance à large bande, ayant des applications militaires et autres. Il fait actuellement l'objet d'un projet de recherches et développement technologique associant le Département de la défense des États-Unis et le ministère de la Défense nationale du Canada. Ce projet vise la construction de transducteurs à large bande commandés à l'aide de matériaux à haute densité d'énergie et destinés à des systèmes de sonar fonctionnant en eaux littorales.

Le transducteur de classe III à large bande a été intégré à un dispositif d'enregistrement de mammifères marins: le système de transmission acoustique à large bande (BATS). Mis au point conjointement par le CRDA et Sensor Technology Limited de Collingwood en Ontario, le BATS a été utilisé par des chercheurs de l'Université Dalhousie de Halifax, (Nouvelle-Écosse) pour étudier les vocalisations de diverses espèces de baleines. À ce jour, les recherches menées au moyen du BATS ont étudié le mimétisme vocal des globicéphales à nageoires longues (cap Breton, été 1999), les structures dialectales des codas des cachalots (Chili, pendant toute l'année 2000) et la localisation acoustique des baleines noires du Nord, espèce menacée (baie de Fundy, été 2000).

Deux dispositifs de commande intégrés (IAD) de faible coût fournis au CRDA par Sensor Technology ont été incorporés à un transducteur à douves expérimental de classe III. Le transducteur commandé par IAD a été étalonné dans l'eau de mer et sa performance a été comparée à celle d'un appareil semblable commandé par une chaîne classique.

Jones, D F, Reithmeier, C.G. 2000. Performance of a Class III barrel-stave flextensional transducer driven by an integrated actuator. DREA TM 2000-025 Centre de recherches pour la défense, Atlantique

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Acknowledgements

The authors would like to thank David Lewis (DREA), Ron Cunningham (Pernix Technology) and Dave Doucette (DREA) for their assistance at the DREA Acoustic Calibration Barge.

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1. Introduction

Flextensional transducer designs have been divided into seven classes based on the morphology of the radiating surfaces of these underwater sound sources [1-4]. In a 1995 technical review article, Jones and Lindberg [5] provided measured performance parameters for experimental and commercial transducers belonging to each class. One of these transducers, known as the Class III barrel-stave flextensional transducer, is a dual-shell design that has a broadband response owing to close coupling between different modes of vibration.

Recently, new piezoceramic integrated actuator drivers (IADs) were developed by Sensor Technology Limited for the Class III barrel-stave transducer. From a production point of view, the main difference between the new actuators and the conventional piezoceramic stacks is that the manufacture of the former requires significantly less manual labour, thereby reducing the overall cost of the transducer.

Two IADs supplied to DREA by Sensor Technology were incorporated into an experimental Class III barrel-stave transducer. This transducer is currently being used in the Broadband Acoustic Transmission System (BATS) developed jointly by DREA and Sensor Technology [6]. The IAD transducer was calibrated in seawater and the performance was compared to a similar unit driven with a conventional stack.

2. Transducer Driver Description

The construction of a Class III barrel-stave flextensional transducer driven with conventional lead zirconate titanate piezoceramic stacks has been discussed in detail by Jones and Reithmeier [7]. The only physical differences between that transducer and the current design are in the driver constituent materials and geometry. These differences are discussed below.

The conventional stack and integrated actuator drivers are illustrated in Figure 1. The conventional stack consists of ten Navy Type III lead zirconate titanate piezoceramic rings connected in parallel electrically. Each ring has an outside diameter of 5.08 cm, an inside diameter of 3.96 cm, and a height of 1.02 cm. The IAD has ten Navy Type I lead zirconate titanate rings connected in parallel and bonded to two machinable glass-ceramic insulators. The inside and outside diameters of the IAD piezoceramic and glass-ceramic rings are the same as those for the conventional rings but the heights are 0.98 cm and 1.88 mm, respectively.

Since the Class III barrel-stave transducer is a dual-shell design [7], each transducer requires two drivers like those shown in the figure. Therefore, the IAD transducer has 4% less piezoelectric ceramic volume than the transducer with the conventional driver.

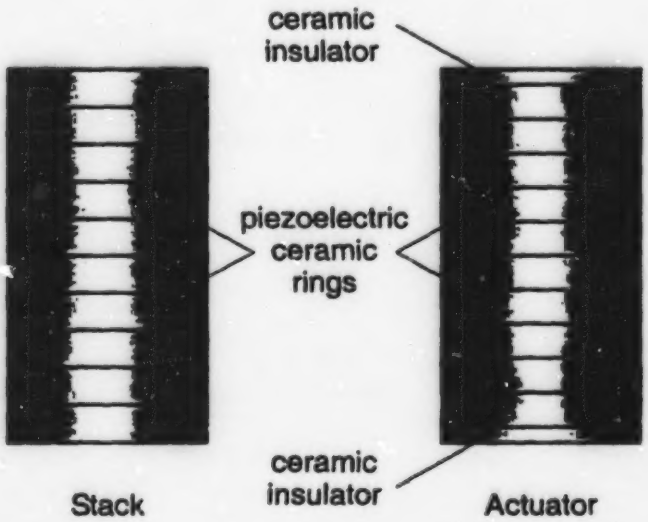

Figure 1. Conventional stack and integrated actuator drivers.

3. Transducer Acoustic Performance

The radial transmitting voltage response (TVR) of the IAD Class III barrel-stave transducer was measured at the DREA Acoustic Calibration Facility on Bedford Basin at a water depth of 14.4 m. An electric field of 320 Vrms/cm was applied to the transducer for this measurement. The radial TVR of the conventional stack-driven Class III barrel-stave transducer was measured in 13.7 m of water using an applied electric field of 440 Vrms/cm. Both TVR curves are shown in Figure 2. The fundamental flexural and longitudinal resonance frequencies, resonance TVR values, and –3 dB quality factors are listed in Tables 1 and 2.

Vertical XZ directivity patterns for the IAD transducer were measured near the resonance peaks in the TVR. Figures 3-6 show the patterns near the 1.3 kHz fundamental flexural resonance, the 3.5 kHz second flexural resonance, the 5.0 kHz longitudinal resonance, and the 9.0 kHz third flexural resonance, respectively. In addition, Figure 7 shows the pattern at the 8.0 kHz notch. Patterns are not available for the conventional transducer discussed in this paper.

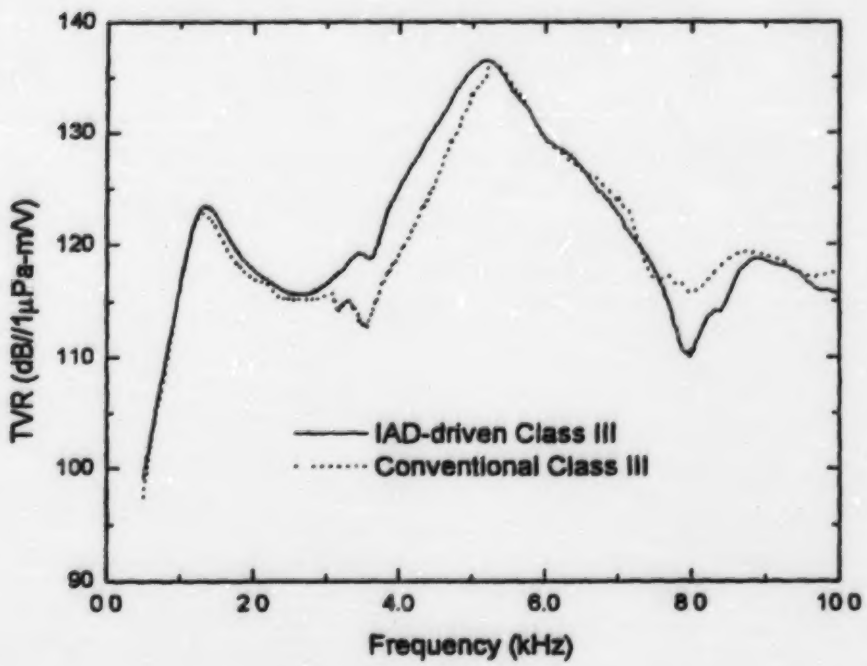

Figure 2. Transmitting voltage response curves.

Table 1. Measured parameters at the fundamental flexural resonance.

TRANSDUCER	FREQUENCY	TVR	Q
	(kHz)	*(dB//1μPa-m/V)*	*(- 3 dB)*
IAD Class III	1.34	123.4	2.4
Conventional Class III	1.31	122.6	2.5

Table 2. Measured parameters at the longitudinal resonance.

TRANSDUCER	FREQUENCY	TVR	Q
	(kHz)	*(dB//1μPa-m/V)*	*(- 3 dB)*
IAD Class III	5.20	136.6	6.4
Conventional Class III	5.27	136.4	8 1

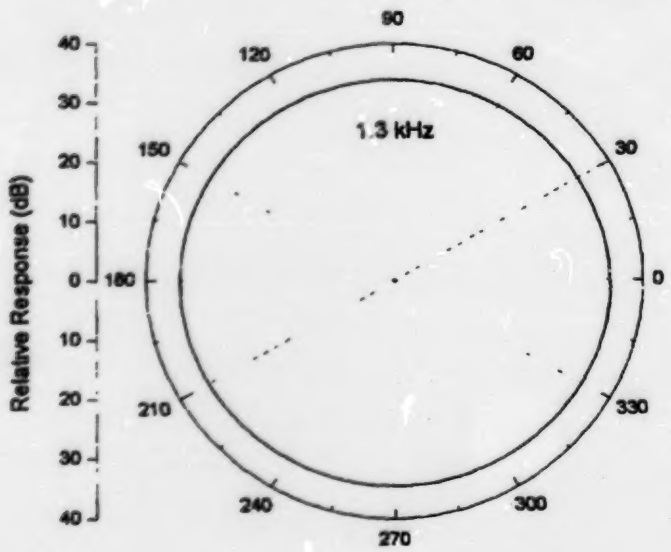

Figure 3. Vertical XZ directivity pattern near the fundamental flexural resonance.

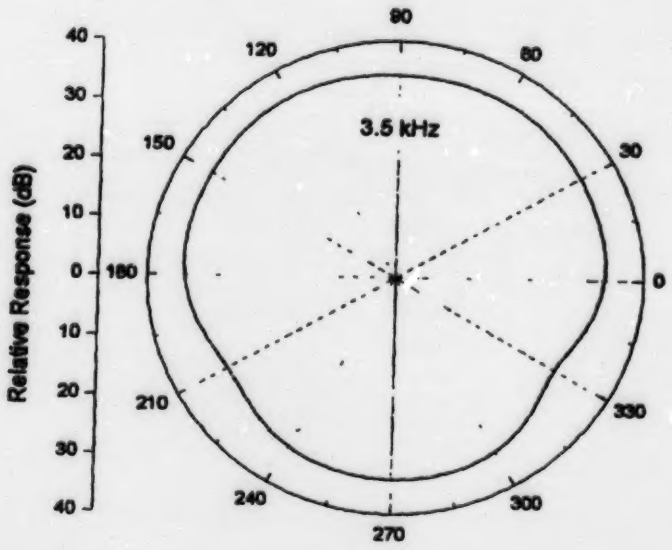

Figure 4. Vertical XZ directivity pattern near the second flexural resonance.

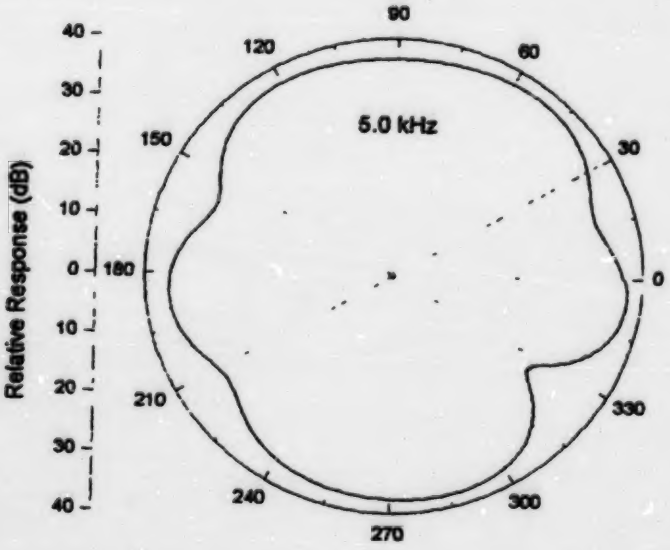

Figure 5. Vertical XZ directivity pattern near the longitudinal resonance.

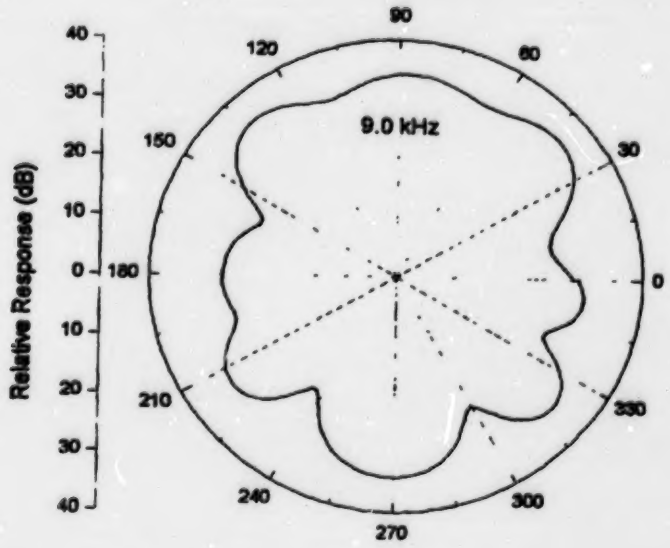

Figure 6. Vertical XZ directivity pattern near the third flexural resonance.

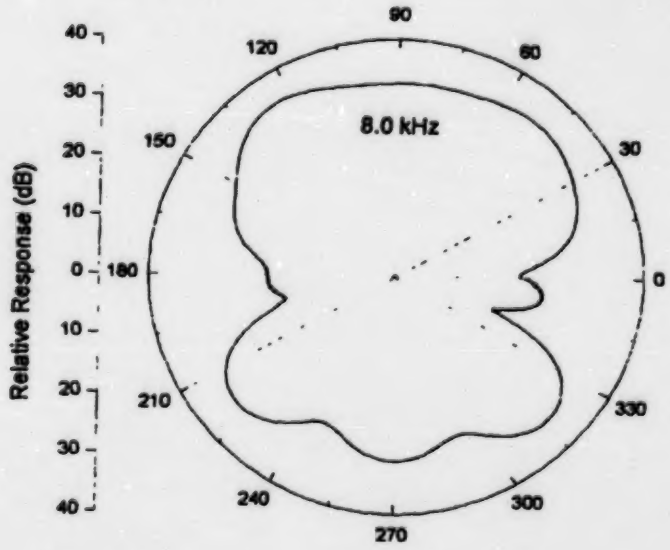

Figure 7. Vertical XZ directivity pattern at the 8.0 kHz notch.

4. Discussion

The data in Figure 2 and Table 1 show that the acoustic performance parameters associated with the fundamental flexural resonance are similar for both the IAD and conventional transducers. The 0.8 dB difference in the TVR values at resonance is smaller than typical calibration errors, which are at best ±1 dB.

The two TVR curves in Figure 2 deviate from each other by as much as 6 dB at the second flexural resonance, which occurs near 3.5 kHz. This relatively weak vibrational mode may be sensitive to transducer assembly tolerances, component manufacturing tolerances, or small differences in component material properties.

It is evident from Figure 2 and Table 2 that the conventional transducer has a higher mechanical quality factor near the 5 kHz longitudinal resonance peak than that of the IAD transducer. This is due to better coupling between the second flexural mode and the longitudinal mode in the latter transducer.

The 9 kHz TVR peaks associated with the third flexural modes are similar for the two transducers but the notch at about 8 kHz is deeper for the IAD transducer (see Figure 2). A possible explanation for this difference comes from considering the epoxy potting at the cable end of the transducer. Throughout the 3-10 kHz frequency band, the presence of this relatively large cylindrical potting (typically 5 cm diameter and 3 cm height) usually leads to asymmetric directivity patterns with more lobes and/or deeper notches towards the cable end of the transducer [8]. Figures 4-7 show these characteristics, since the cable end of the transducer is located at 270° in the polar plots. Because the potting on the conventional transducer has about 44% less volume than that on the IAD transducer, the directivity patterns, and consequently the TVR values, can be different, especially at high frequencies where the patterns contain a higher number of smaller lobes. Therefore, minor angular shifts in the small lobes at 0° and 180° in Figure 7, caused by having different potting geometries, can significantly affect the depths of the notches in the TVR curves.

5. Conclusions

A broadband Class III barrel-stave flextensional transducer driven by an integrated actuator has four coupled TVR resonance peaks below 10 kHz. Below 3 kHz the response is similar to that of a Class III barrel-stave transducer driven by a conventional stack. From 3 to 5 kHz the IAD transducer produces as much as 6 dB more sound pressure level than the conventional Class III due to better coupling between the second flexural and longitudinal modes. A deep notch in the response near 8 kHz may be due to the sensitivity of narrow radial lobes to vibrational asymmetries caused by the cable potting.

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4 AUTHORS (Last name, first name, middle initial If military, show rank, e g Doe, May John E)

Dennis F. Jones and Charles G. Reithmeier

5 DATE OF PUBLICATION (month and year of publication of document)	6a NO OF PAGES (total containing information Include Annexes, Appendices, etc)	6b NO OF REFS (total cited in document)
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7 DESCRIPTIVE NOTES (the category of the document, e g technical report, technical note or memorandum If appropriate, enter the type of report, e g interim, progress, summary, annual or final Give the inclusive dates when a specific reporting period is covered)

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